

INTERNET BASED ROUNDNESS & CYLINDRICITY ANALYSIS

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Abstract: This paper presents an Internet Based Roundness and Cylindricity Analysis System, which applies Java and Internet technology to engineering metrology. The package includes most of the standardized and advanced analysis tools for roundness and cylindricity. The most distinct feature of this package is that it can run on the Internet, which enables platform independent and remote analysis of roundness and cylindricity data.

Keywords: Roundness, Cylindricity

1 INTRODUCTION

The software systems for roundness and cylindricity analysis currently available are local to instruments that are built by different instrument companies. There are always some differences in algorithms used in all the existing packages. Moreover, as large corporations outsource manufacturing, the need for remote access of data and process troubleshooting is steadily increasing. So there is a growing need to have a common platform with standardized tools to analyze raw data independently. With the evolution of the Internet and the enhanced power of computers, it is possible to build a software package that can be run on the Internet.

2 SOFTWARE DESIGN AND IMPLEMENTATION

The requirement of the software is to build an on-line tool for measurement data analysis. An object oriented design concept is applied to the software design of the package [1]. For better modeling, the software development process uses the Unified Modeling Language (UML), a language that produces drawings comparable in their intent to the blueprints long used in other technical disciplines. The process makes it practical to base much of the development on reusable components. In developing the software, an incremental approach was taken towards gathering requirements, designing the software, and implementing and testing it. This approach was taken so that the requirements could be modified to increase the scope after an iteration of the development cycle. This approach was also essential to add different features to software according to different customer requirements. The main components of the system are the user interface classes and the background processing classes. All the classes of the system have been developed using pure Java (JDK 1.1). The plotting classes use a special Java 2D graph package, which was covered by the GNU General Public License [1]. A front end is based on Java AWT package to ensure proper running and displaying on current available web browsers. The main tools used during the course of this project were JDK 1.1, Java 2D Graph Package by GNU, Rational Software for UML (Unified Modeling Language), HTML 3.2 (Hyper Text Markup language).

3 ROUNDNESS ANALYSIS

The software offers a unique approach to analyze roundness and cylindricity over the Internet. It integrates currently available tools on different measurement machines, and introduces some special purpose analysis tools.

3.1 Filtering Techniques

A total of five different filters are included in the software for roundness and cylindricity analysis.

- TwoCR Filter with 75% transmission.
- Gaussian Filter with 50% transmission.
- Spline Filter with 50% transmission.
- FFT (Fast Fourier Transform) Filter.
- FFT Bandpass Filter.

3.1.1 2RC filter

2RC low pass filtering is based on the amplitude transmission function given in Figure 1. The cutoff frequency in undulations per revolution (UPR) is defined as the frequency at which the transmission is 75%.

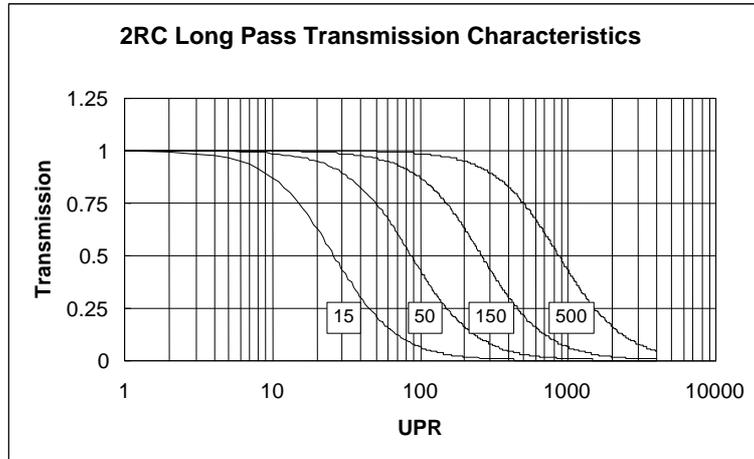


Figure 1. Transmission characteristic for the low-pass (long-pass) 2RC filter having cut-off frequencies, $f_c = 15, 50$ and 150 upr.

3.1.2 Gaussian filter

The Gaussian filter transmits waves from 1 upr and attenuates profile undulations progressively in the undulation region around the characteristic cut-off upr number. The cutoff frequency (in UPR) is defined as the frequency at which the transmission is 50%. The attenuation function (transmission characteristic) is given by:

$$\frac{a_1}{a_0} = e^{-p \left(\frac{af}{f_c} \right)^2} \quad \text{and} \quad a = \sqrt{\frac{\ln(2)}{p}}$$

- Where:
- a_0 = amplitude of sine wave undulation before filtering
 - a_1 = amplitude of a given sine wave of frequency, f , after filtering.
 - f_c = cut-off frequency (in upr) of the low pass filter
 - f = frequency of a given sine wave (in upr)

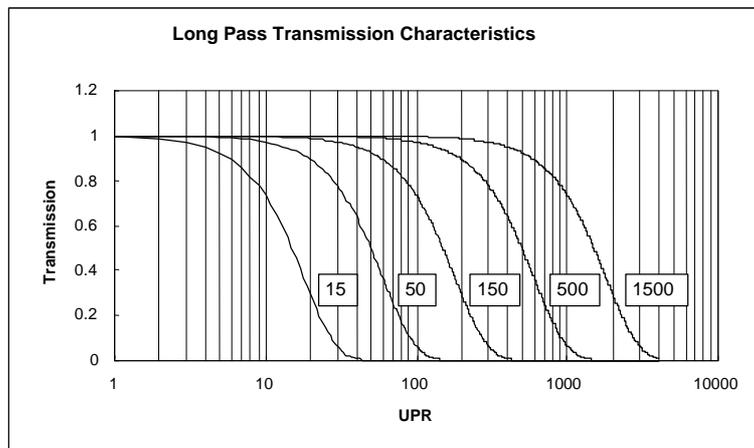


Figure 2. Transmission characteristic for the low-pass (long-pass) Gaussian filter having cut-off frequencies, $f_c = 15; 50; 150; 500; 1500$ upr.

3.1.3 Spline filter

The implementation of spline filtering is based on the algorithm developed by Michael Krystek [3], which yields a good approximation to the transfer function of the phase-correct filter, but avoids the disadvantages of this filter type.

3.1.4 Fourier filter

All frequencies up to and including the cut-off ω_{pr} are transmitted 100%. All frequencies higher than the cut-off are completely suppressed.

3.2 Fitting Algorithms

Most spindle based roundness measuring machines use precision spindle to create a relative motion between the part being measured and the displacement transducer radially mounted perpendicular to the axis of rotation. The output of the transducer is the combined information of the out-of-roundness of the part and the relative eccentricity of the part axis with respect to the spindle axis. The output of the transducer is a radius suppressed eccentric circle. Since the eccentricity is usually small compared to the radius of the part, the high order terms are omitted leading to a limaçon as an approximation. Four fitting algorithms for roundness and one fitting algorithm for cylindricity are included in this package:

- Least Square Reference
- Minimum Zone Reference
- Maximum Inscribed Reference
- Minimum Circumscribed Reference
- Least Square Cylinder Reference

3.2.1 Least Square Reference

For least squares best fitting, we start off with the basic linear equation of eccentric circle:

$$r(q) = R + a \cos q + b \sin q$$

For a set of measured data points, (R, a, b) are obtained by

$$R = \frac{\sum_{i=1}^n r_i}{n}, \quad a = \frac{2 \sum_{i=1}^n (r_i \cos q_i)}{n}, \quad b = \frac{2 \sum_{i=1}^n (r_i \sin q_i)}{n}$$

where r_i represents the individual measured data points with index i , q_i is the angle of data points, and n is the number of data points.

3.2.2 Minimum Zone Reference (MZ)

The minimum zone limaçon can be visualized by replacing two concentric figures generating a zone by the equivalent form of a single figure and a zone width "h" referred to that figure. The single reference limaçon will be defined with a symmetrically placed zone $\pm h$. The MZ problems then becomes that of minimizing h subject to the constraints:

$$R + a \cos q_i + b \sin q_i + h \geq r_i$$

$$\text{and } R + a \cos q_i + b \sin q_i - h \leq r_i$$

for data points in polar form (r_i, q_i) , $i = 1, 2, \dots, n$. Figure 3 shows the minimum zone fitting result for a set of roundness data.

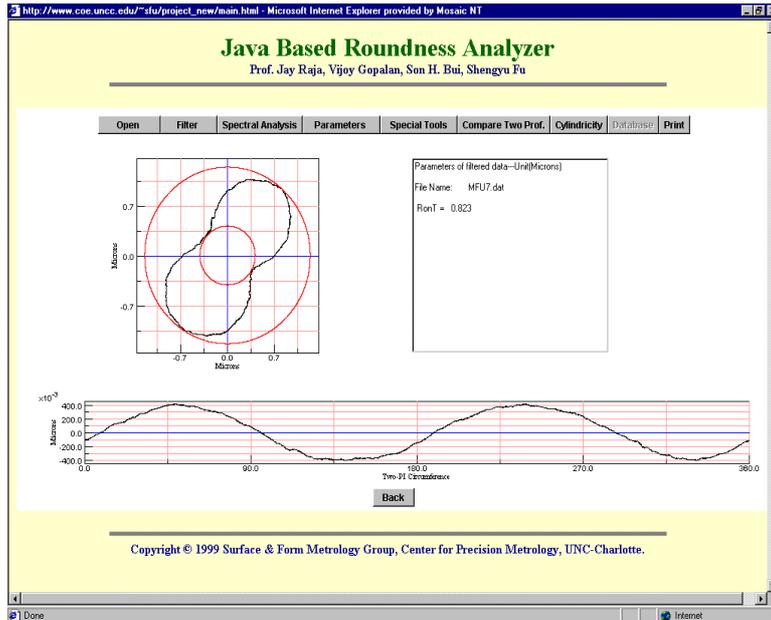


Figure 3. Minimum zone fitting

3.2.3 Minimum Circumscribed Reference (MC)

The MC fit requires finding a limaçon of minimum radius such that the limaçon lies completely outside the data representing the nominal circle being measured. The mathematical representation of the above definition based on the equation of a limaçon would be

$$R + a \cos q_i + b \sin q_i \geq r_i$$

for data points in polar form (r_i, q_i) , $i = 1, 2, \dots, n$.

3.2.4 Maximum Inscribed Reference (MI)

The MI fit is one in which all data points lie outside the reference limaçon. This can be viewed as an extension of the MC fit described above, where the signs are reversed in the basic limaçon equation. The formulation for the MI limaçon will be

$$R + a \cos q_i + b \sin q_i \leq r_i$$

which is essentially the same as $-(R + a \cos q_i + b \sin q_i) \geq -r_i$ for all i .

Algorithms proposed by D.G. Chetwynd were used for the different limaçon fits described above [2].

3.2.5 Least Square Cylinder Reference

A simplified equation for a cylinder is given below [6]

$$R(q, z) = (a_0 + a_1 z) \cos q + (b_0 + b_1 z) \sin q + R_0$$

The procedure for least-squares fitting of a cylinder is as follows:
Considering the equation:

$$\Delta r_i(q_i, z) = (a_0 + a_1 z) \cos q_i + (b_0 + b_1 z) \sin q_i + R_0$$

where $q_i = 0 \dots 360^\circ$, and $i = 1, \dots, n$ is the number of data points.

Thus we have n linear equations and five unknowns $(a_0, b_0, a_1, b_1, R_0)$ for each data trace. The equation can be written in matrix form as $d = AP$:

$$\begin{bmatrix} \Delta r_1 \\ \Delta r_2 \\ \cdot \\ \cdot \\ \cdot \\ \Delta r_k \end{bmatrix} = \begin{bmatrix} \cos q_1 & \sin q_1 & z_1 \cos q_1 & z_1 \sin q_1 & 1 \\ \cos q_2 & \sin q_2 & z_2 \cos q_2 & z_2 \sin q_2 & 1 \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cos q_k & \sin q_k & z_k \cos q_k & z_k \sin q_k & 1 \end{bmatrix} \begin{bmatrix} a_0 \\ b_0 \\ a_1 \\ b_1 \\ R \end{bmatrix}$$

where $k = m \cdot n$, m is number of traces, n is number of points per traces. Using singular value decomposition, we can solve out this matrix equation and get a vector solution containing the parameters $(a_0, b_0, a_1, b_1, R_0)$.

3.3 Parameters

Four parameters for roundness namely, RonT: Maximum peak to valley deviation, RonP, Maximum peak to reference deviation, RonV: Maximum reference to valley deviation, RonQ: RMS of the profile to reference deviation are computed. For cylindricity, OOC: Maximum peak to valley deviation is computed.

4 SPECIAL TOOLS

4.1 Multi-cutoff Filtering

For better understanding of different frequency components of the profile, it's necessary to look at the parameter variation after filtering with different cutoffs. The analysis package offers a feature to filter using four different cutoff values. Figure 4 shows the multi-cutoff filtering results for a roundness profile.

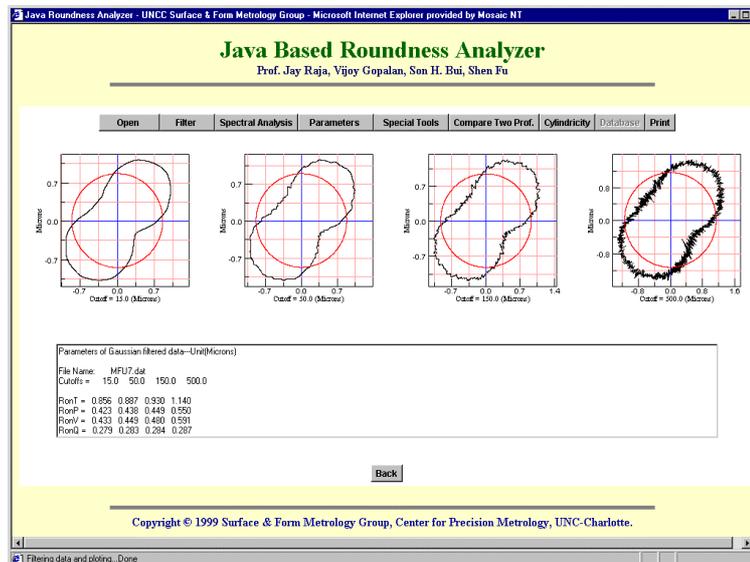


Figure 4. Multi-cutoff filtering

4.2 Multi-filter Filtering

This tool permits the comparison of different filters implemented in the software. This tool also is useful to evaluate the effect of filters.

4.3 Reversal Technique for Error Separation

In some measurement situations requiring high precision, the out-of-roundness of the spindle motion has to be taken into account. This method is based on the work done by Donaldson, which essentially uses reversal technique for error separation [4]. Processing two profiles measured from two setups (index probe to 0^0 & 180^0).

In set-up 0^0 ,

$$T_1(q) = P(q) + S(q)$$

while in set-up 180^0 , if the probe is in normal priority,

$$T_{2p}(q) = P(q) - S(q)$$

otherwise,

$$T_{2s}(q) = -P(q) + S(q)$$

where $P(q)$ -- part error, $S(q)$ -- spindle error.

In each case, the spindle error and workpiece profile can be separated. A procedure to separate using measured data $T_1(q)$, $T_{2p}(q)$ or $T_{2s}(q)$ has been implemented.

4.4 Multi-step Method for Error Separation

The multi-step method needs 12 profiles from 12 measurements obtained by indexing the part every 30^0 . It is a more precise method to separate part error and spindle error [5]. A procedure to separate spindle and part error has been implemented for data obtained from 30^0 indexing.

5 SOFTWARE TESTING

All algorithms of the package were tested using theoretical data. Also comparisons have been done between the analysis result of the package and of software on commercial system. The package will be field tested in industry.

6 LIMITATION AND FUTURE WORK

We plan to build a database and link it with the package, which can allow global users to insert measured data, query for specific datasets, and select specific datasets for analysis. A database also can provide a repository for profiles from different manufacturing and measurement process, which is valuable for comprehensive study of processes. To allow multiple users to access analysis package and database at the same time and increase the computing capacity of package, we plan to move to a three-tier architecture that is widely used in most enterprise computing software.

7 CONCLUSION

Internet based Roundness & Cylindricity analysis offers a unique way of analyzing circular form data over the Internet. It introduces distributed computing to metrology and permits global access through Internet. It also offers a set of unique features, which are not available in most current commercial software as single collection.

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